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# CONSTITUTIVE RESPONSE OF TWO PLASTIC-BONDED EXPLOSIVE BINDER MATERIALS AS A FUNCTION OF TEMPERATURE AND STRAIN-RATE.

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**Abstract.** Recently, interest has been shown concerning the mechanical response of plastic-bonded explosives (PBX) and propellants to enable the development of predictive materials models describing the mechanical behavior of these composites. Accordingly, detailed information about the constitutive response is crucial. Compression measurements were conducted on two explosive formulation binders, extruded Estane<sup>TM</sup> 5703 (hereafter referred to as Estane) and plasticized Estane as a function of temperature from -60°C to +23°C using a specially-designed split Hopkinson pressure bar (strain rate of  $\approx 2800 \text{ s}^{-1}$ ) and quasi-statically (strain rates from  $\approx 0.001$  to  $1 \text{ s}^{-1}$ ) using a hydraulic load frame. The mechanical response of the Estane was found to exhibit a stronger dependency on strain rate and temperature and higher flow strength for similar test conditions of the materials tested. Plasticized Estane was less sensitively dependent on strain rate and temperature. The visco-elastic recovery of both binders is seen to dominate the mechanical behavior at temperatures above the glass transition temperature ( $T_g$ ). The binders exhibited increasing elastic loading moduli,  $E$ , with increasing strain rate or decreasing temperature, which is similar to other polymeric materials. There is a pronounced shift in the apparent  $T_g$  to higher temperatures as the strain rate is increased. At low strain rates the binders exhibit a yield behavior followed by a drop in the flow stress which may or may not recover. At high strain rates the load drop does not occur and the flow stresses level out. A discussion of the Hopkinson bar technique as applied to polymeric or low impedance materials is described in detail.

# **CONSTITUTIVE RESPONSE OF TWO PLASTIC-BONDED EXPLOSIVE BINDER MATERIALS AS A FUNCTION OF TEMPERATURE AND STRAIN-RATE**

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**ABSTRACT-** Compression measurements were conducted on two explosive binders, extruded Estane<sup>TM</sup> 5703 (Estane) and plasticized Estane as a function of temperature (-60°C to +23°C) and strain rate (0.001 s<sup>-1</sup> to  $\approx$  2800 s<sup>-1</sup>). The mechanical response of the Estane was found to exhibit a stronger dependency on strain rate and temperature and higher flow strength for similar test conditions than plasticized Estane. Visco-elastic recovery dominates the mechanical behavior above the glass transition temperature ( $T_g$ ). The apparent  $T_g$  shifts to higher temperatures as the strain rate is increased. The yield and flow stress behavior of these materials at the different strain rates will also be discussed in greater detail.

**INTRODUCTION:** It is well known that increasing the strain-rate strongly affects the mechanical response of polymers in compression (Walley [1994]). Increasing the strain rate leads to higher moduli because the polymer chains have reduced relaxation time (Ward [1983]). There is a strong need for predictive constitutive model descriptions of polymers for use in large-scale finite-element simulations of damage and deformation. New continuum models, based on actual physical and chemical mechanisms, to describe complex loading processes must account for complex phenomenology including temperature, strain rate, orientation effects like crosslinking and chain stretching, or texture (created by extrusion or directional formation), and aging effects on mechanical performance if a predictive capability is to be achieved. Conventional methods are easily used to measure the mechanical properties of polymers at low strain rates. However, high strain rate characterization using the split Hopkinson pressure bar (SHPB) requires more rigor. Recent studies by the authors' detail procedures that help obtain accurate, reproducible data for visco-elastic materials like polymers (Blumenthal [1999], Gray [2000]). Uniaxial compression tests were performed from quasi-static to high-strain rates for temperatures from -60°C to +23°C on these polymers and it has been found that: a) the effective elastic modulus is strongly influenced by strain rate and temperature, b) viscoelastic-plastic behavior is indicated below  $T_g$ , and c) specimen-size and lubrication effects are critical due to very slow stress wave propagation through polymers. In general, the compressive strength and the loading modulus of polymeric materials increases with decreasing temperature and increasing strain rate.

**PROCEDURES, RESULTS AND DISCUSSION:** Two materials were studied. Estane 5702 manufactured by BF Goodrich Company. The static glass transition temperature ( $T_g$ ) of Estane is  $-31^\circ\text{C}$ , a melting temperature of  $\sim 105^\circ\text{C}$ . The second material, plasticized Estane, consists of 49% Estane 5703, 49% BDNPA-F Nitroplasticizer, and 2% Irgonox. The addition of the plasticizer (1) lowers the static glass transition temperature to  $\sim -40^\circ\text{C}$ ; (2) causes the polymer strength to decrease, but the toughness and flexibility are increased, and (3) acts as a ‘lubricant’ to promote the sliding of the polymer chains, and to reduce the degree of entanglement. Cylindrical compression specimens were machined following published procedures (Blumenthal [1999]).

The compressive stress-strain response of the binders was found to be strongly dependent on strain rate and temperature (Fig. 1). The apparent loading modulus, defined as the slope of the stress-strain curve prior to “plastic”, unrecoverable deformation, of Estane at  $23^\circ\text{C}$  increased from  $\sim 3\text{ MPa}$  at  $0.001\text{ s}^{-1}$  to  $\sim 21\text{ MPa}$  at  $2400\text{ s}^{-1}$ . The loading modulus increased to  $6.5\text{ MPa}$  at  $-3^\circ\text{C}$ ,  $65\text{ MPa}$  at  $-30^\circ\text{C}$ , and  $577\text{ MPa}$  at  $-40^\circ\text{C}$  for a strain rate  $0.001\text{ s}^{-1}$ . The modulus of plasticized Estane at  $23^\circ\text{C}$  changed from  $\sim 0.46\text{ MPa}$  at  $0.001\text{ s}^{-1}$  to  $\sim 3.27\text{ MPa}$  at  $2200\text{ s}^{-1}$ . The addition of plasticizer lowers the  $T_g$  and decreases the strength of Estane. In order to compare the two materials lower temperature tests were conducted.

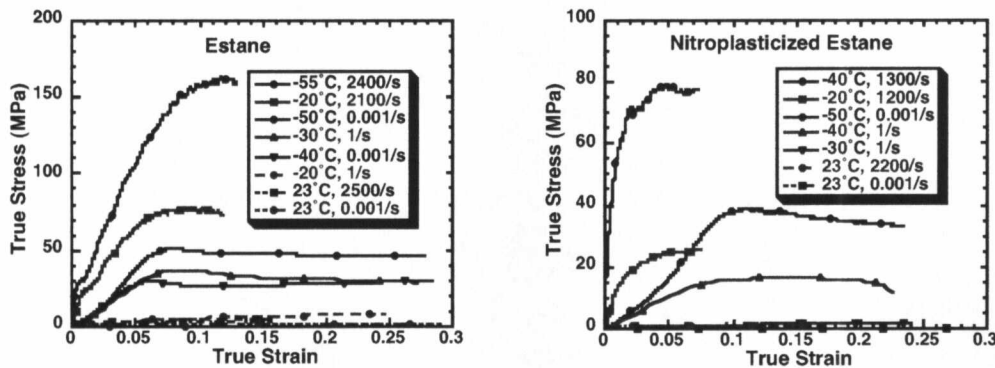


Fig. 1. Stress-strain properties of the binders as a function of temperature and strain rate.

The apparent loading modulus was  $1.24\text{ MPa}$  at  $-15^\circ\text{C}$ ,  $4.36\text{ MPa}$  at  $-40^\circ\text{C}$ , and  $366\text{ MPa}$  at  $-50^\circ\text{C}$  for a strain rate of  $0.001\text{ s}^{-1}$ . Reducing the temperature through the apparent  $T_g$  of  $\sim -40^\circ\text{C}$  produced almost 2 orders of magnitude change in the apparent loading modulus for plasticized Estane, twice the value seen in the Estane. There is a sharp transition from visco-elastic to elastic-plastic behavior near the apparent  $T_g$  (Fig. 2).  $T_g$  shifts by  $\sim 10^\circ\text{C}$  as the strain rate increased from  $0.001\text{ s}^{-1}$  to  $1\text{ s}^{-1}$  further increase to  $\sim 2200\text{ s}^{-1}$  caused a  $\sim 25^\circ\text{C}$  shift for Estane and  $\sim 15^\circ\text{C}$  shift for plasticized Estane. Low Strain rate testing showed the yield strain consistently exceeded of 5% strain. (The SHPB technique is not valid for determining yield properties (Gray [2000])). Obviously, the addition of plasticizer affects the material behavior significantly above  $T_g$ . The mechanical responses above  $T_g$  were reproducible, but replicating tests near or below  $T_g$  was much more problematic. The pronounced influence of strain rate and temperature on these materials is similarly observed in other ductile polymers.

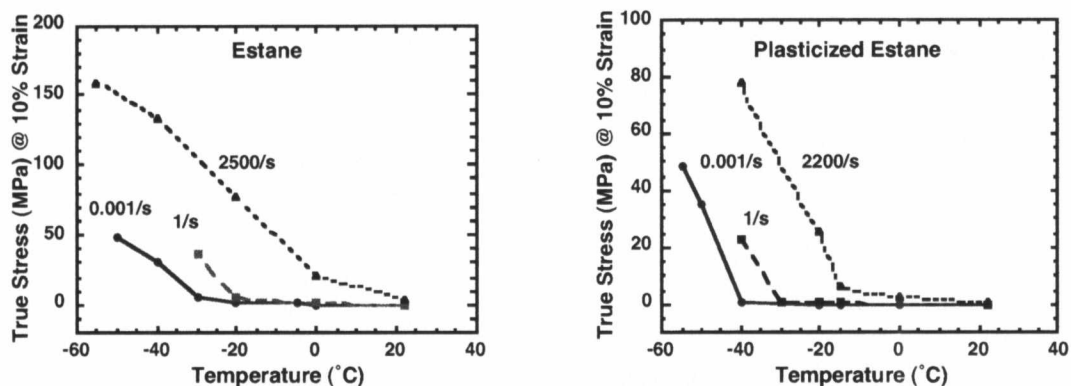


Fig. 2. Stress versus Temperature showing the shift in glass transition.

**CONCLUSIONS:** The following results for the binders can be drawn: 1) changing the temperature or strain rate effects the flow strength, the apparent loading modulus, and the strain-at-maximum-stress; 2) scatter near or below  $T_g$  was more pronounced due to the high temperature sensitivity of the materials. Processing variability and chain orientation could also cause scatter at low temperatures due to the reduced chain mobility; 3) increasing the strain rate clearly increases the apparent glass transition temperature in a nonlinear manner.

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